CASE 22

Functional Evaluation of an Electrophotographic Process

Abstract: In this study, methods of developing an electrophotographic process, which consist of many elements, were discussed. There are two approaches: to divide the entire system into several subsystems and evaluate each one individually, or is to evaluate the entire system. From the study we determinedthat the function of the entire system can be evaluated and part of the subsystem can be optimized at the same time.

1. Introduction

Electrophotography is widely used for plain-paper photocopy machines and laser printers. Figure 1 outlines a popular imaging device. As photosensitive material turns in the direction of the arrow, it is evenly charged on the surface, exposed by a laser beam modulated according to an image, developed by toner, transferred to transfer material such as paper, and the surface cleaned. Toner image transferred onto transfer material is fixed and carried out of a machine. The imaging device in Figure 1 can be regarded as consisting of functional subsystems such as electrical charge, exposure, development, transfer, and fixer.

In developing this device, two different approaches are possible: (1) organize a total system after optimizing each subsystem, or (2) evaluate the functionality of the entire system continuously from the beginning. The former can be ideal if there is no interaction among separated subsystems. However, we should consider that we have some interaction in case of a complex system such as an electrophotography device. In the following, we explain the method to integrate subsystems.

2. Generic Function

As shown in Figure 1, an imaging device is a system converting input image data into fixed toner images. Their relationship should be one-to-one and linear and controlled by units that are as small as possible in terms of adhesion. Once we achieve all of them, we can obtain both satisfactory gradation and vividness. Therefore, an ideal electrophotography system should reproduce dots of image data precisely with dots formed by toner. More specifically, an ideal characteristic has the following relationship between the square root of the number of image data dots, M, and the square root of the dot area of toner image, y:

$$Y \text{ (square root of dot area)} = \beta M \text{ (square root of the number of image data} \quad (1)$$

Figure 2 shows this relationship.

Next we describe a parameter design based on the foregoing idea. Control factors can be selected from multiple subsystems or as common factors from such as developer. In this example, we assigned 12 factors to an L_{27} orthogonal array. As noise factors we chose factors that are special to electrophotography and significantly influential on results. We selected the following:

1. Paper type (popular noise factor, very influential on transfer and fixing)
2. Difference between the total and core areas of a dot (specific to electrophotography)

 Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

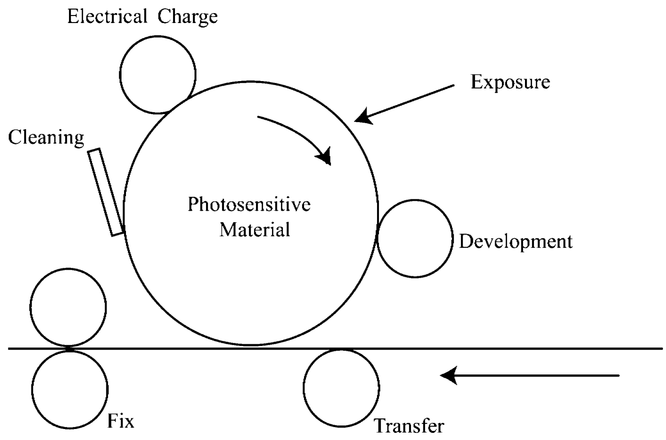

Figure 1
Electrophotography device

3. Maximum dot and minimum dot (specific to electrophotography)

As shown in Figure 3, quite often a dot formed on transfer material by toner is either separated or small portions are scattered around a large portion. As to factor 2, we regarded as noise the difference between the total sum of areas included in a dot, defined as one portion, and the area of its core area only. For factor 3 we set a dimensional difference between maximum and minimum dots to noise.

3. SN Ratio

After producing images using preset conditions, we measured magnified dot areas using image analysis software. The results are shown in Table 1. We surmised that the proportionality of input and output dot sizes would deviate if the beam diameter of the exposure light were large. This theory will be evaluated in the analysis. In short, we removed divergence from the proportionality, M_{res}, from a signal

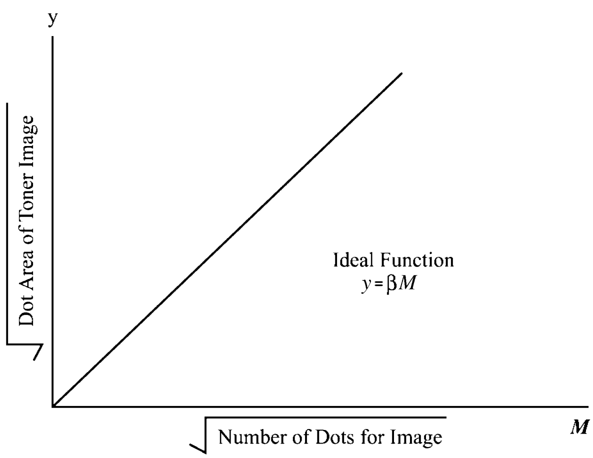

Figure 2
Generic function of imaging

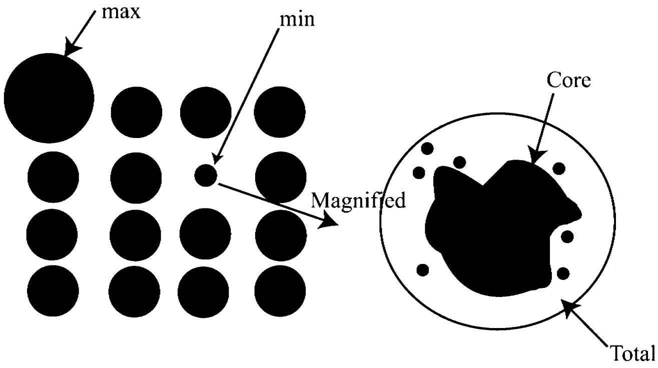

Figure 3
Noise factor in electrophotography image

effect, M. On the other hand, other variations, N, can be decomposed into the three error factors 1, 2, and 3 ($\beta \times$ paper type, $\beta \times$ gap, and $\beta \times$ size) and an error, e. Detailed calculations for the SN ratio and sensitivity were as follows.

Total variation:

$$S_T = 19.7^2 + 33.9^2 + \cdots + 54.6^2 = 54{,}167 \qquad (f = 32) \tag{2}$$

Total error variance:

$$V_N = \frac{S_T - S_M}{28} = 13.82 \tag{3}$$

SN ratio:

$$\eta = 10 \log \frac{(1/8r)(S_\beta - V_e)}{V_N} = 12.02 \text{ dB} \tag{4}$$

Sensitivity:

$$S = 10 \log \frac{1}{8r}(S_\beta - V_e) = 23.43 \text{ dB} \tag{5}$$

4. Optimal Configuration and Confirmatory Experiment

Table 2 shows control factors assigned to an L_{27} orthogonal array. As a result of parameter design, we

Table 1
Example of square root of dot area of toner image

Paper Type	Gap	Min./Max.	Signal (Square Root of Number of Dots) 1	2	3	4	Linear Equation
Plain	Total	Min.	19.7	33.9	42.0	51.9	420.9
		Max.	23.5	35.9	49.0	56.7	469.0
	Core	Min.	13.7	31.4	39.9	49.9	395.9
		Max.	22.1	35.0	47.8	55.2	456.4
Overhead Projector	Total	Min.	23.5	37.0	47.4	53.4	453.3
		Max.	27.1	41.6	51.1	56.0	487.6
	Core	Min.	13.7	34.3	43.9	49.8	413.2
		Max.	22.5	39.3	48.8	54.6	465.9

Table 2
Control factors

Control Factor	Level 1	Level 2	Level 3
Developer			
A: ingredient content	A_{1}[a]	A_2	A_3
B: ingredient content	B_{1}[a]	B_2	B_3
C: ingredient type	C_{1}[a]	C_2	C_3
D: ingredient content	D_1	D_{2}[a]	D_3
E: manufacturing condition (quantity)	E_1	E_{2}[a]	E_3
Device			
F: device condition (quantity)	F_{1}[a]	F_2	F_3
G: device condition (quantity)	G_1	G_{2}[a]	G_3
H: device condition (quantity)	H_1	H_{2}[a]	H_3
I: device condition (quantity)	I_1	I_{2}[a]	I_3
J: device condition (quantity)	J_{1}[a]	J_2	J_3
K: device condition (quantity)	K_{1}[a]	K_2	K_3
L: device condition (type)	L_1	L_{2}[a]	L_3

[a] Current and optimal configurations.

Table 3
Result of confirmatory experiment

Configuration	Estimation	Confirmation
(*a*) Original Analysis		
Current	10.33	9.39
Optimal	16.61	13.21
Gain	6.28	3.82
(*b*) Reanalysis		
Current	12.94	10.80
Optimal	19.71	16.57
Gain	6.77	5.77

obtained factor effect plots (Figure 4). Based on the optimal and current configurations, we conducted a confirmatory experiment and obtained the results shown in Table 3*a*.

After we had investigated the reason for a difference between estimation and confirmation, we noticed that there was no control factor to improve the min./max. noise factor, so we proposed remov-

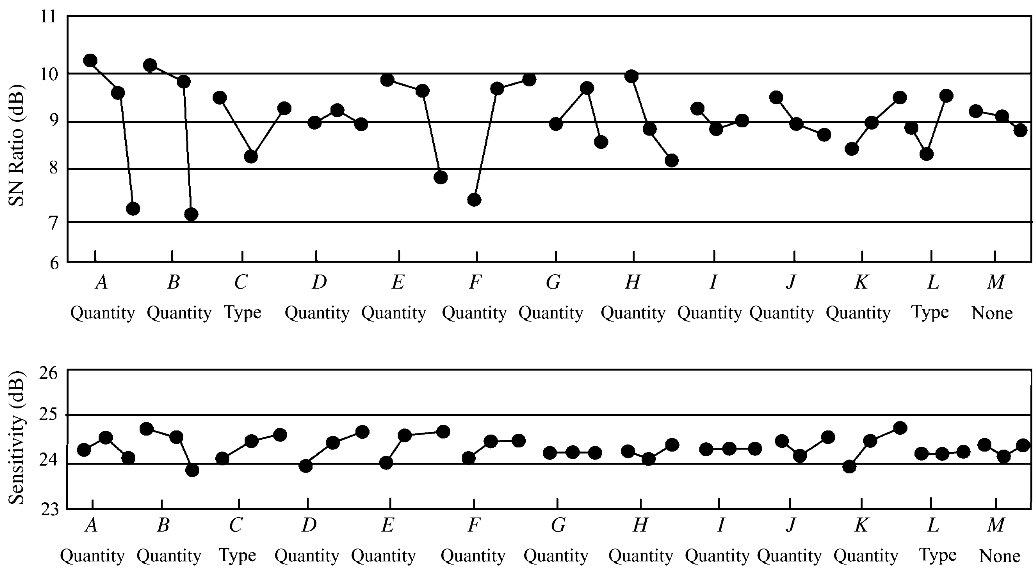

Figure 4
Response graphs of original analysis corresponding to Table 3*a*

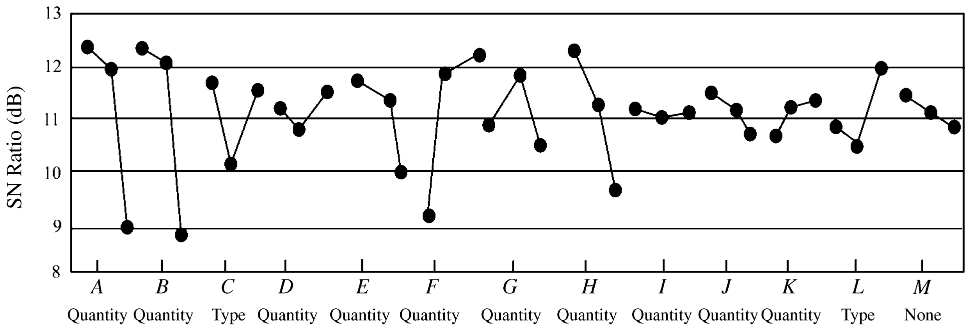

Figure 5
Response graphs of reanalysis corresponding to Table 3*b*

ing this contributing part. More specifically, in place of V_N as computed in equation (3), we used V'_N to calculate the SN ratio and sensitivity:

$$V'_N = \frac{S_{\beta\times\text{error}} + S_{\beta\times\text{gap}} + S_e}{27} = 8.43 \qquad (6)$$

The eventual response graph was as shown in Figure 5, and the optimal configuration was the same as the original configuration shown in Table 3*a*. In the results of the confirmatory experiment shown in Table 3*b*, we see fairly good reproducibility of gain.

This procedure was applicable not only to the optimization of a total system but also to that of partial systems such as the development or transfer processes. As a consequence, we can ensure at an earlier stage that the total system is appropriate. One problem with this method is that we cannot use it without knowing the total system. Thus, when this method is used, we need a flexible application such as partial optimization determining the generic functions of subsystems.

Reference

Hisashi Shoji, Tsukasa Adachi, and Kohsuke Tsunashima, 2000. A study of functional evaluation for electrophotographic process. *Quality Engineering*, Vol. 8, No. 5, pp. 54–61.

This case study is contributed by Hisashi Shoji.